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A SUMMARY OF ENVIRONMENTAL EFFECTS OF SPACE SHUTTLE LAUNCHES AT JOHN F. KENNEDY SPACE CENTER, FLORIDA AFTER THE FIRST 24 LAUNCHES

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ABSTRACT

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TWENTY-FOUR LAUNCHES OF THE SPACE SHUTTLE HAVE OCCURRED SINCE 1981. THE ENVIRONMENTAL EFFECTS OF THOSE LAUNCHES HAVE BEEN CATEGORIZED INTO NEAR-FIELD SHORT-TERM ACUTE, NEAR-FIELD LONG-TERM CHRONIC AND FAR-FIELD LONG-TERM CHRONIC. IMPACTS ARE GENERATED IN THE NEAR-FIELD BY THE DEPOSITION OF 3.4×10^3 kg OF HCl AND 7.1×10^3 kg OF PARTICULATES CONSISTING OF PAD SURFACE DEBRIS AND Al_2O_3. FAR-FIELD (> 1 km) DEPOSITION OF HCl VARIED FROM 25 TO 5300 mg/m^2 BASED ON LEAF WASHING AND DROP ANALYSES. PLANT COMMUNITY STRUCTURE AND COMPOSITION HAS BEEN PERMANENTLY ALTERED IN AN IMPACT ZONE OF 50 ha NEAR-FIELD. NO CHANGES HAVE BEEN NOTED OUTSIDE THE NEAR-FIELD. SOIL LEACHATE STUDIES INDICATE A CUMULATIVE DECREASE IN pH OVER 24 LAUNCHES, INCREASES IN Al, Cu, Fe, AND Zn CONCENTRATIONS AND DECREASED BUFFERING CAPACITY. SURFACE WATERS HAVE SHOWN ONLY TEMPORARY CHANGES (1—3 DAYS) IN pH DUE TO ACUTE LAUNCH EFFECTS. LOCAL FISH KILLS OCCUR AT EACH LAUNCH, HOWEVER, LONG-TERM FISH POPULATION STUDIES ARE INCOMPLETE AT THIS TIME. STUDIES CONTINUE TO ASSESS LONG-TERM IMPACTS ON SEDIMENT AND BENTHOS. OVERALL IMPACTS ARE ASSOCIATED WITH THE NEAR-FIELD LAUNCH EXHAUST CLOUD EFFECTS RATHER THAN FAR-FIELD DEPOSITION.

INTRODUCTION

LAUNCHES OF THE SPACE SHUTTLE FROM JOHN F. KENNEDY SPACE CENTER PRODUCE ENVIRONMENTAL IMPACTS RESULTING FROM THE LAUNCH EXHAUST CLOUD. MAJOR CONSTITUENTS OF THE CLOUD ARE CARBON DIOXIDE (CO_2). WATER (H_2O), ALUMINUM OXIDE (Al_2O_3), AND HYDROGEN CHLORIDE (HCl). CLOUD FORMATION OCCURS AS A RESULT OF THE COMBINED EFFECTS OF THE IGNITION OF THE SOLID ROCKET MOTORS (SRM), THE SPACE SHUTTLE MAIN ENGINES (SSME), AND THE SIMULTANEOUS DUMPING OF OVER 1100 KILOLITERS OF SOUND SUPPRESSION AND COOLING WATER ONTO THE LAUNCH PAD. ATOMIZATION OF THE DELUGE WATER OCCURS IN THE TURBULENCE OF THE ROCKET EXHAUSTS, AND THESE DROPLETS COAGULATE WITH Al_2O_3 PARTICULATES WHICH RAPIDLY SCAVENGE HYDROGEN CHLORIDE GAS PRODUCING ACIDIC DEPOSITION. THE EXHAUST CLOUD IS DIRECTED NORTHWARD BY THE STRUCTURE OF THE FLAME TRENCH AND BEGINS TO RISE AS THE HORIZONTAL VELOCITY DECREASES. THE CLOUD RISES, ENTRAINS AMBIENT AIR UNTIL REACHING A STABILIZATION HEIGHT AND IS CARRIED DOWNRANGE BY PREVAILING WINDS.

NEAR-FIELD ACUTE EFFECTS ARE PRODUCED BY DEPOSITION FROM THE CLOUD AS IT SWEEPS ACROSS THE SOIL, VEGETATION, AND LAGOONAL WATERS. GENERALLY, NEAR-FIELD EFFECTS HAVE OCCURRED WITHIN 0.5 km OF LAUNCH PAD 39A ALTHOUGH THEY HAVE EXTENDED UP TO 1.0 km AWAY. SINCE THE pH OF DROPLETS IN THIS CLOUD CAN BE < 0.5, NEAR-FIELD EFFECTS CAN BE SEVERE AND INCLUDE ACUTE VEGETATION DAMAGE, TEMPORARY REDUCTION IN SOIL pH, AND DECREASED pH IN NEARBY SURFACE WATERS RESULTING IN SMALL LOCAL FISH KILLS.

NEAR-FIELD AND FAR-FIELD ENVIRONMENTAL MONITORING ACTIVITIES ASSOCIATED WITH LAUNCH EVENTS, AND AS PART OF A LONG-TERM ENVIRONMENTAL MONITORING PROGRAM, HAVE CHARACTERIZED THE ENVIRONMENTAL LOADING AND MAJOR EFFECTS OF THE EXHAUST MATERIALS. SHORT-TERM, ACUTE EFFECTS OF LAUNCH AND, TO A LESSER DEGREE, LONG-TERM CUMULATIVE EFFECTS ON THE NATURAL ENVIRONMENT HAVE BEEN DETERMINED. DATA FOR THE FIRST 24 LAUNCHES OF THE SPACE SHUTTLE ARE ANALYZED FOR EFFECTS ON SOILS, VEGETATION, AQUATIC SYSTEMS AND WILDLIFE.

THE PURPOSE OF THIS PAPER IS TO PRESENT, IN SUMMARY FASHION, THE RESULTS FROM SELECTED MONITORING ACTIVITIES.

CONCLUSIONS

DEPOSITION OF LAUNCH CLOUD HCl OVER A 50 ha NEAR-FIELD AREA RESULTS IN :

- SHORT-TERM, ACUTE ENVIRONMENTAL EFFECTS INCLUDING:
  - A RAPID DECLINE IN pH (APPROXIMATELY 6.0 TO 7.0 UNITS) OF LAGOONAL SURFACE WATERS WHICH TAKE UP TO 72 HOURS TO RETURN TO BACKGROUND
  - SMALL FISH KILLS DUE TO TEMPORARY REDUCTION OF pH OF LAGOONAL SURFACE WATERS
  - SEVERE DAMAGE TO EXPOSED VEGETATION
  - DECLINE IN SOIL LEACHATE pH AND INCREASE IN NUTRIENT/METAL LEACHING; THESE RETURN TO NEAR BACKGROUND WITHIN SEVEN DAYS

- LONG-TERM, CHRONIC ENVIRONMENTAL EFFECTS INCLUDING :
  - REDUCTION IN VEGETATION COVER AND SPECIES COMPOSITION RESULTING IN PLANT COMMUNITY STRUCTURE CHANGES
  - REDUCTION IN SOIL pH AND BUFFERING CAPACITY
  - CHANGES IN AQUATIC FAUNA (FISH AND BENTHOS) SPECIES COMPOSITION AND STRUCTURE ARE PROBABLE BUT UNKNOWN AT THIS TIME

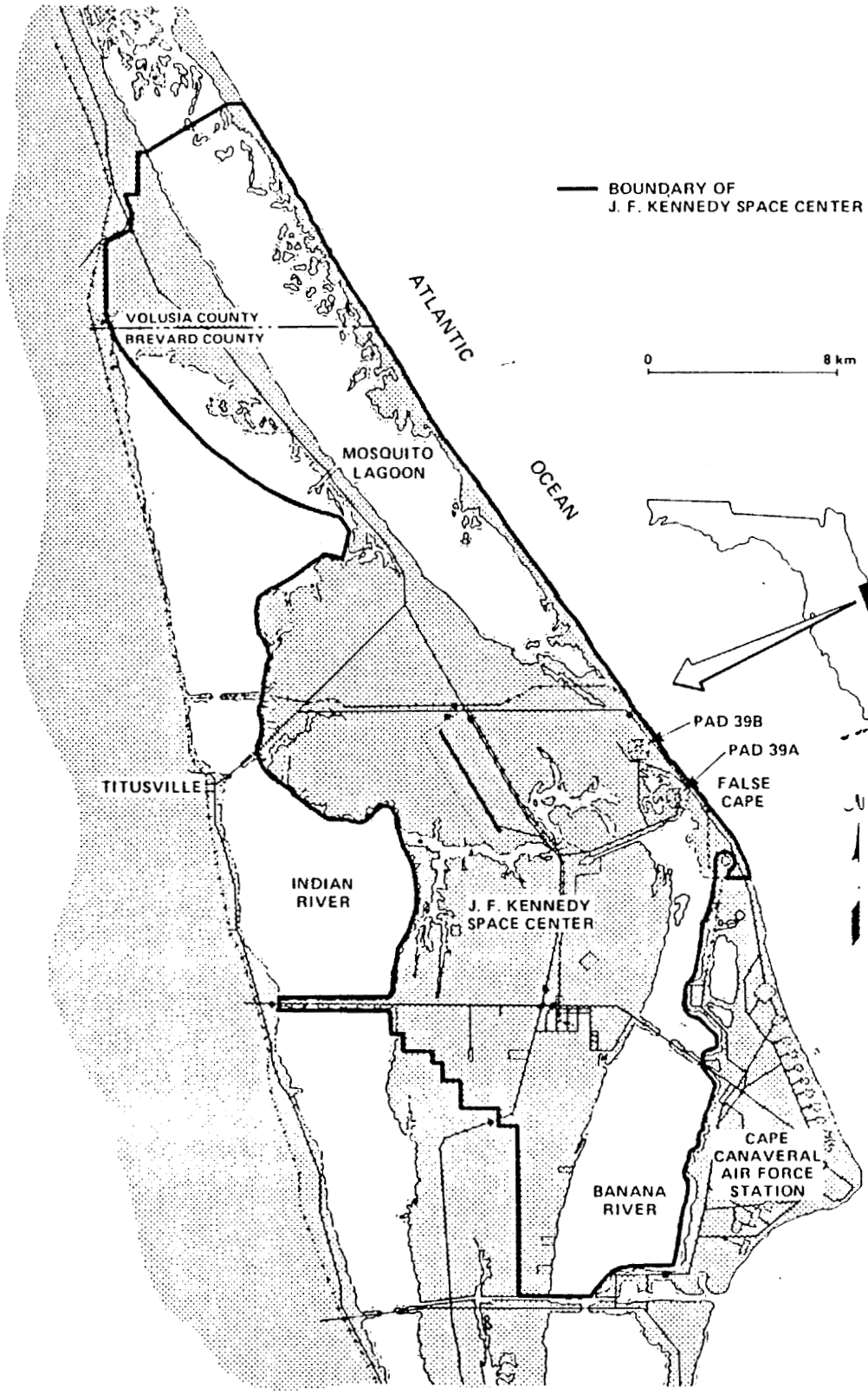
DEPOSITION OF LAUNCH CLOUD PARTICULATES OVER A 50 ha NEAR-FIELD AREA RESULTS IN :

- SIGNIFICANT LONG-TERM, CHRONIC ENVIRONMENTAL EFFECTS INCLUDING :
  - INCREASED LEVELS OF Al, Fe AND Zn IN SOIL LEACHATES
  - CHANGES IN SOIL STRUCTURE AND SEDIMENT CHARACTERISTICS ARE PROBABLE BUT EFFECTS ARE UNKNOWN AT THIS TIME

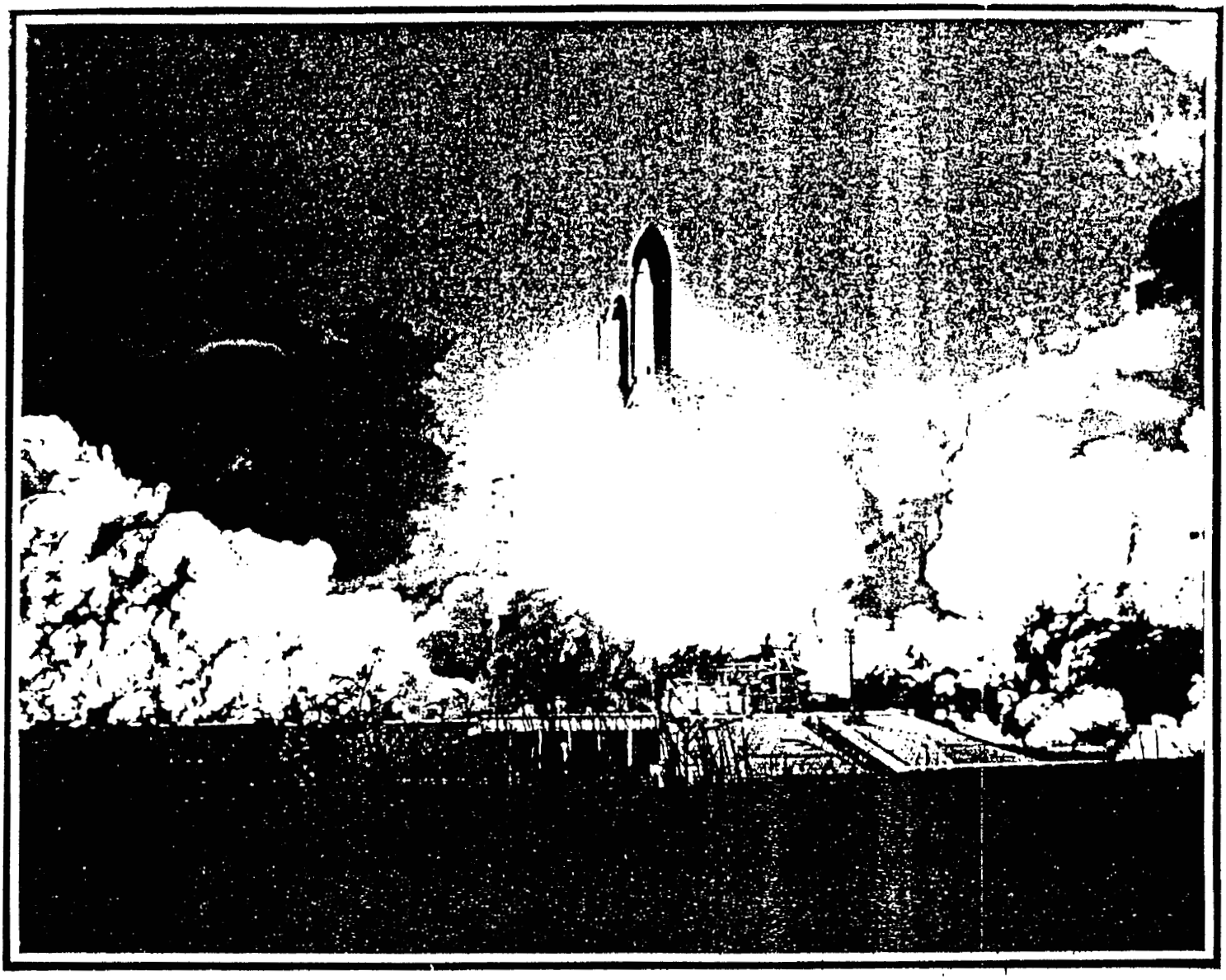
DEPOSITION OF LAUNCH CLOUD HCl AND PARTICULATES OVER THE FAR-FIELD AREA RESULTS IN :

- SHORT-TERM, ACUTE ENVIRONMENTAL EFFECTS INCLUDING :
  - LEAF SPOTTING FROM ACID DROPS WHICH ARE HIGHLY VARIABLE IN NUMBER AND DISTRIBUTION DEPENDING ON AMBIENT CONDITIONS
  - Al_2O PARTICULATES DEPOSITION WHICH IS HIGHLY VARIABLE IN AMOUNT AND DISTRIBUTION DEPENDING ON AMBIENT CONDITIONS

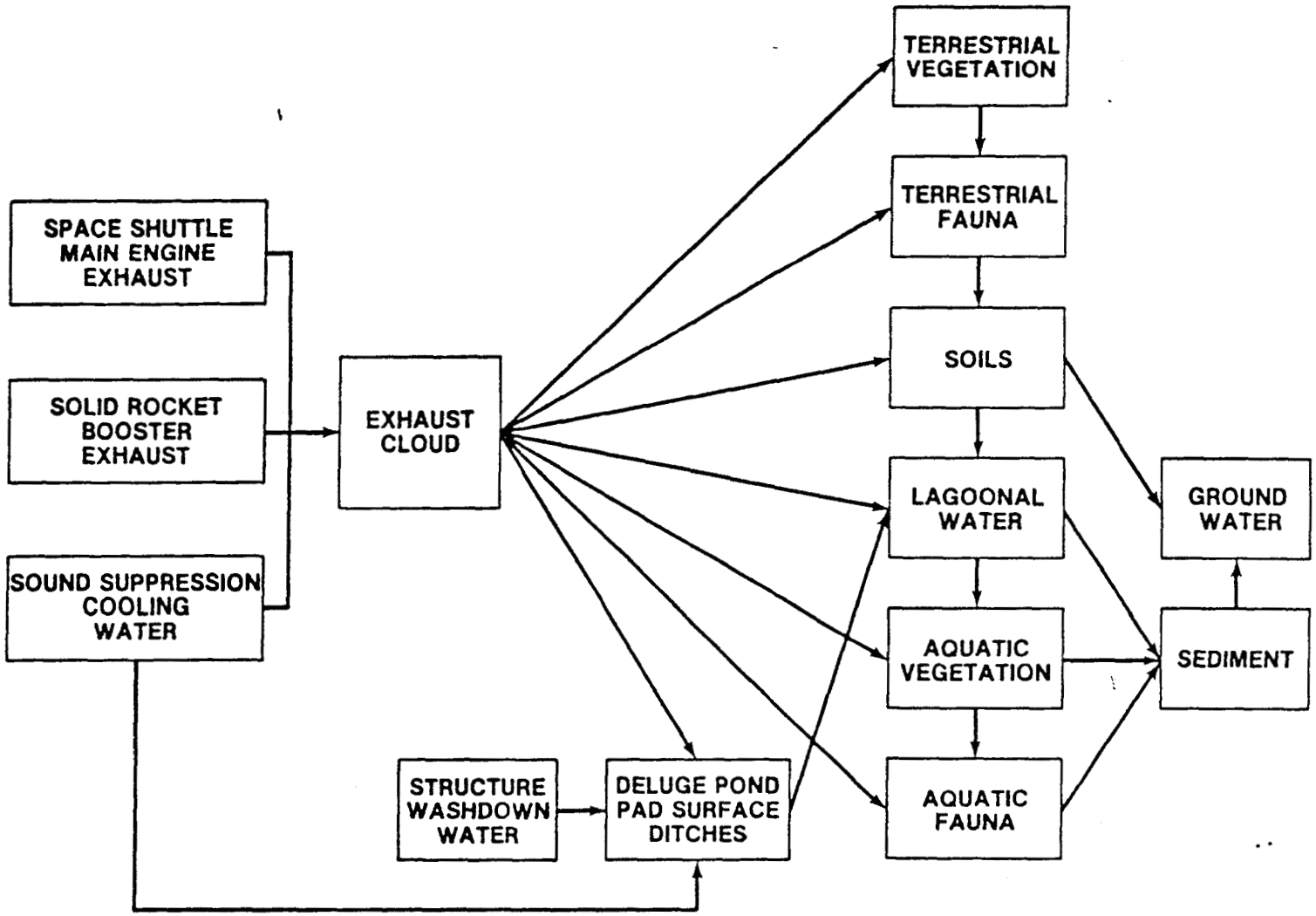
- LONG-TERM, CHRONIC ENVIRONMENTAL EFFECTS WHICH ARE NEGLIGIBLE DUE TO WIDESPREAD AND NON-CUMULATIVE NATURE OF THE DEPOSITION



JOHN F. KENNEDY SPACE CENTER IS LOCATED ON MERRITT ISLAND IN EAST CENTRAL FLORIDA. IT INCLUDES 57,000 HECTARES OF COASTAL BARRIER ISLAND ECOSYSTEMS INCLUDING WETLAND, UPLAND, LAGOON AND DUNE COMPLEXES

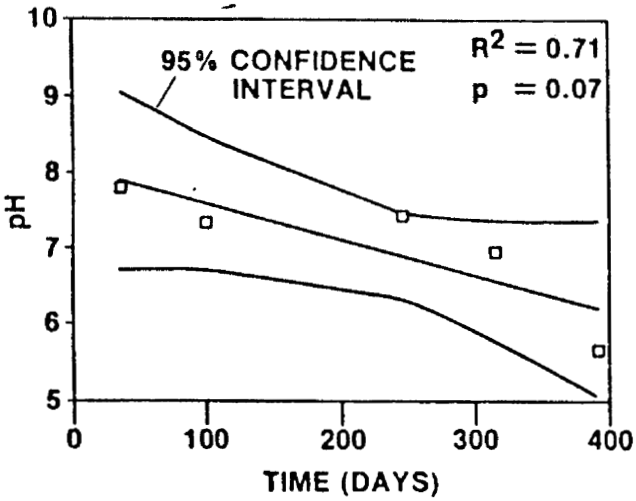


EXHAUST FROM THE SHUTTLE MAIN ENGINES (LEFT) AND EXHAUST FROM THE SOLID ROCKET BOOSTERS (RIGHT) COUPLED WITH SOUND SUPPRESSION AND COOLING WATER FORM THE GROUND CLOUD (RIGHT). THE CLOUD IS FORMED DURING THE 8-10 SECONDS REQUIRED FOR THE VEHICLE TO CLEAR THE PAD TOWER.

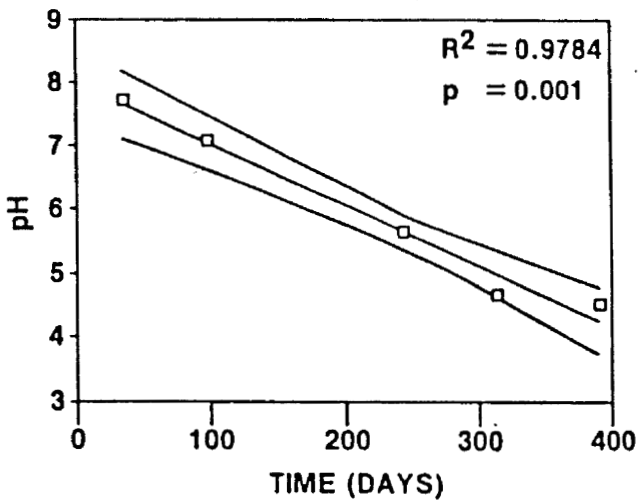


A SIMPLIFIED DIAGRAM OF LOADING OF LAUNCH MATERIALS INTO THE NATURAL ENVIRONMENT. EACH LAUNCH PRODUCES APPROXIMATELY 3.4×10^3 kg OF HCl AND 7.1×10^3 kg PARTICULATES WHICH ARE DEPOSITED IN THE NEAR-FIELD AREA. ACUTE EFFECTS OCCUR IMMEDIATELY FROM EXPOSURE TO CLOUD DEPOSITED HCl WHILE LONG-TERM CUMULATIVE EFFECTS OCCUR WITH REPEATED EXPOSURES.

LEACHATE pH FROM SOILS WITH FIVE EXPOSURES

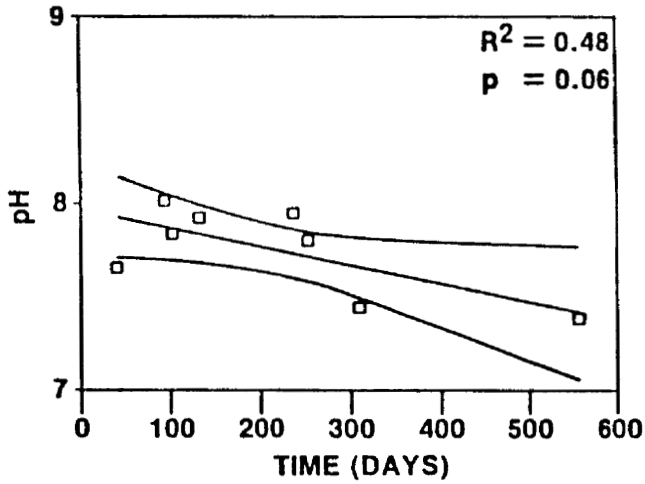


LEACHATE pH FROM SOILS WITH FOURTEEN EXPOSURES

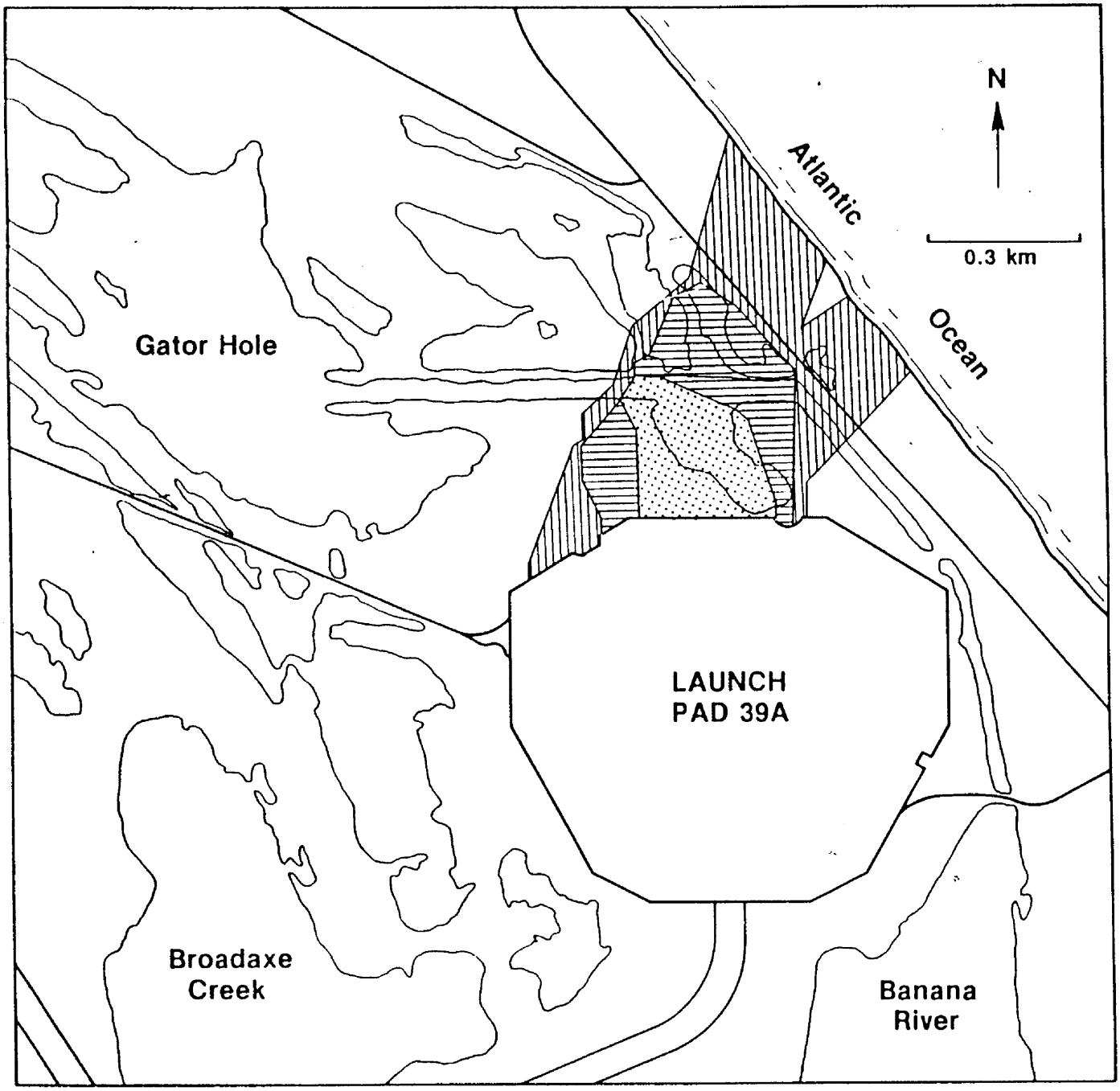


THE DECREASE IN SOIL LEACHATE pH IMMEDIATELY POST LAUNCH BECAME GREATER WITH REPEATED EXPOSURE

LEACHATE pH FROM SOILS WITH UP TO FOURTEEN EXPOSURES. SAMPLES TAKEN BETWEEN LAUNCHES AFTER RECOVERY TO NEAR BACKGROUND



SOIL LEACHATE pH WAS EFFECTIVELY REDUCED BY APPROXIMATELY 0.5 UNITS AFTER FOURTEEN LAUNCHES



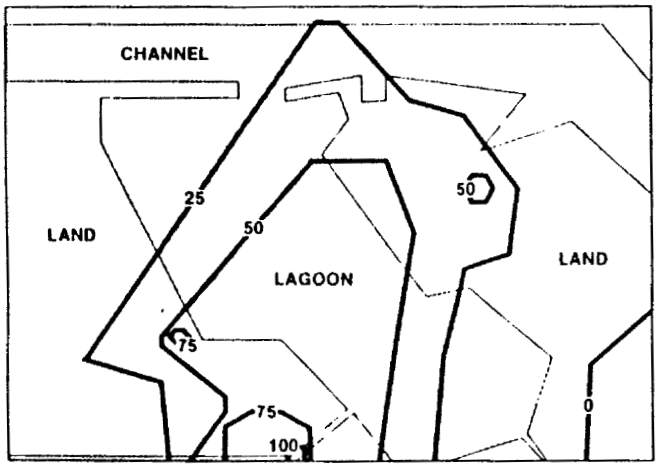
CUMULATIVE NEAR-FIELD LAUNCH DEPOSITION

1 2-5 > 5

NEAR-FIELD DEPOSITION FROM THE FIRST 19 LAUNCHES FELL IN A GENERALLY PREDICTABLE AREA WITHIN 1.0 km OF PAD 39A

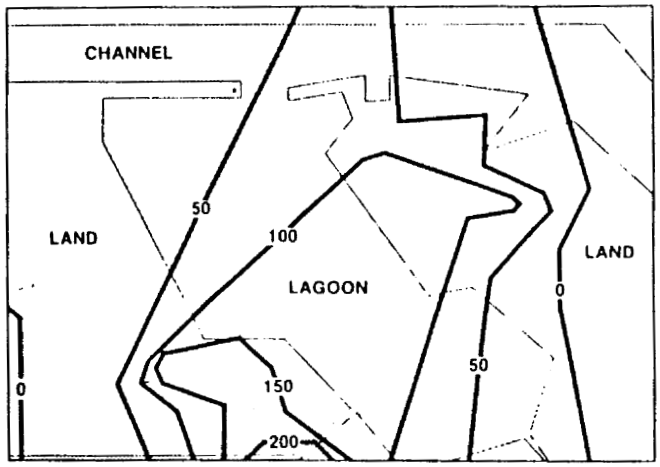
CHLORIDE DEPOSITION: LAUNCH OF STS-11

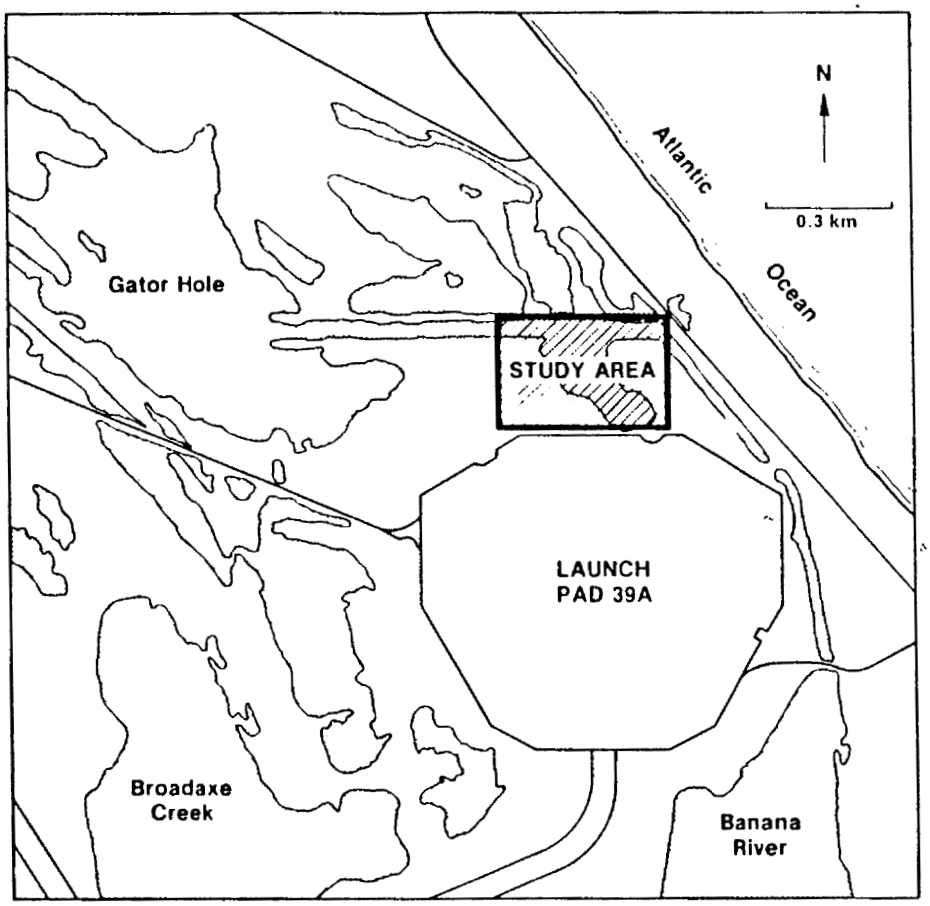
(grams/square meter)



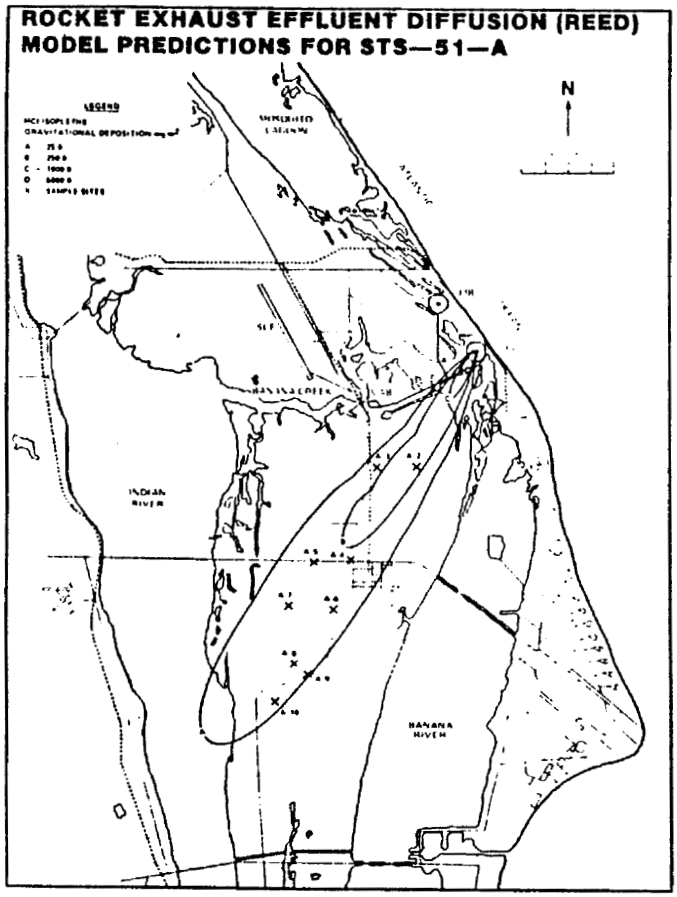
PARTICULATE DEPOSITION: LAUNCH OF STS—11

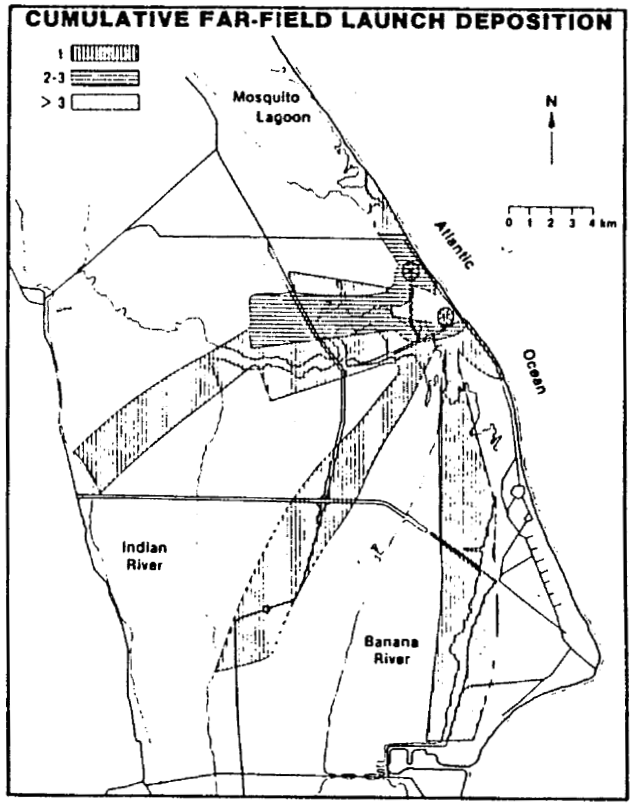
(grams/square meter)





NEAR-FIELD DEPOSITION QUANTITIES AND DISTRIBUTION WERE DETERMINED USING A GRID OF BULK COLLECTORS IN THE 12 ha STUDY AREA





FAR—FIELD CHLORIDE DEPOSITION FROM STS—51—B DETERMINED FROM LEAF SAMPLES

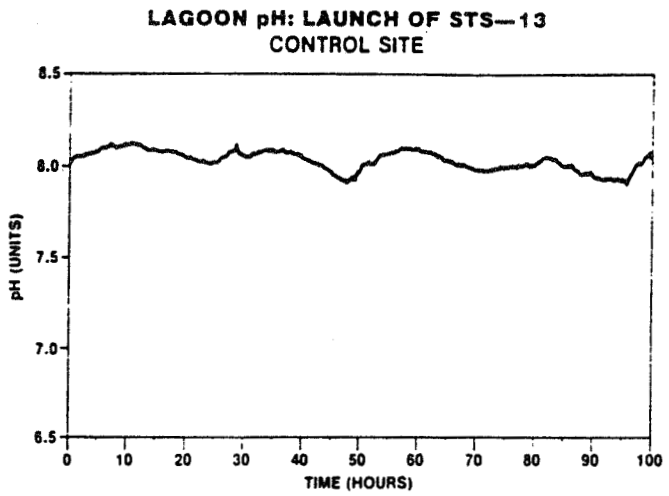
SITE NUMBER	NUMBER OF DROPS PER m^2 MEAN	NUMBER OF DROPS PER m^2 RANGE
A—1	2312	1447—2997
A—2	3286	1550—5477
A—3	5747	5042—6465
A—4	2722	1685—4018
A—5	519	384—778
A—6	4147	2203—5573
A—7	421	259—648
A—8	1361	648—2333
A—9	5832	3240—9072
A—10	7776	7776

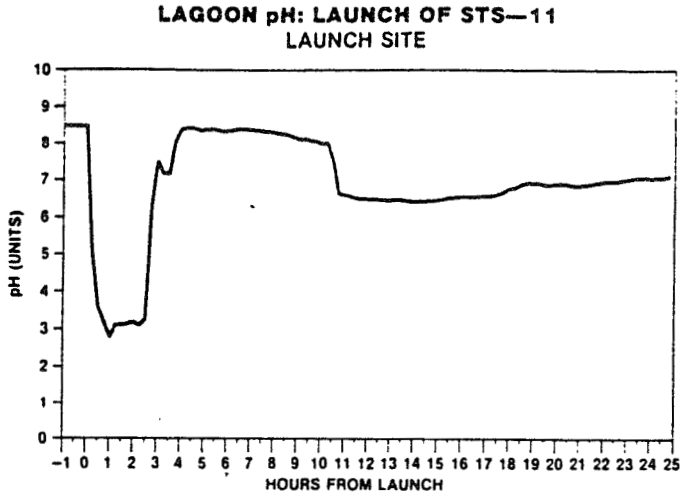
SITE SPECIES	AMOUNT OF CHLORIDE PER UNIT AREA (mg/m^2)	[1] CHLORIDE DEPOSITION (mg/m^2)	[2] MODEL PREDICTION (mg/m^2)
B—1 CATTAIL #1	4778.04	4245.96	6722
B—1 CATTAIL #2	5835.33	5303.25	6722
B—2 GROUNDSEL #1	154.08	- - - -	1000
B—2 GROUNDSEL #2	118.57	- - - -	1000
B—3 GROUNDSEL #1	1171.19	922.64	1000
B—3 GROUNDSEL #2	952.01	703.46	1000
B—4 GROUNDSEL (CONTROL)	248.55	- - - -	0
B—5 CATTAIL (CONTROL)	532.08	- - - -	0

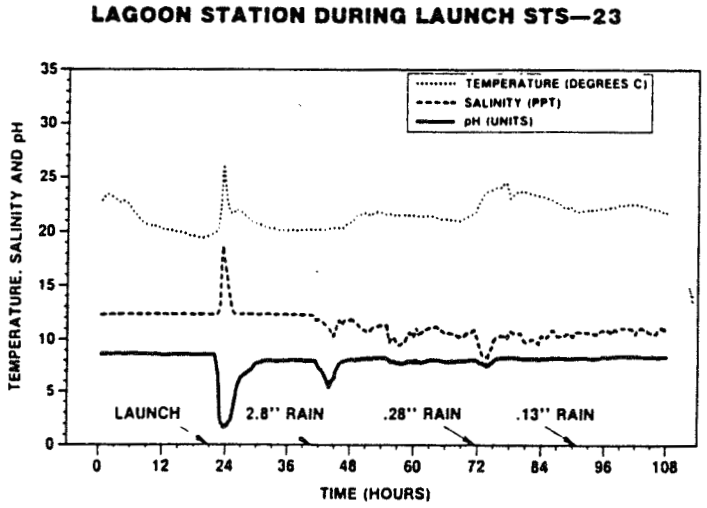
[1] DEPOSITION CALCULATED AS AMOUNT PER UNIT AREA MINUS CONTROL FOR THAT SPECIES.

[2] PREDICTED DEPOSITION BASED ON ROCKET EXHAUST EFFLUENT DIFFUSION (REED) MODEL, MAXIMUM CENTERLINE CALCULATIONS USED FOR SITE B—1 AND ISOPLETH MAP FOR OTHER SITES.

A ROCKET EXHAUST DIFFUSION MODEL WAS USED TO PREDICT THE FAR—FIELD DEPOSITION PATTERNS. THESE PATTERNS AND AMOUNTS OF HCl DEPOSITION WERE VERIFIED BY DROP COUNTS AND BY LEAF WASHINGS FROM VEGETATION IN THE CLOUD PATH.

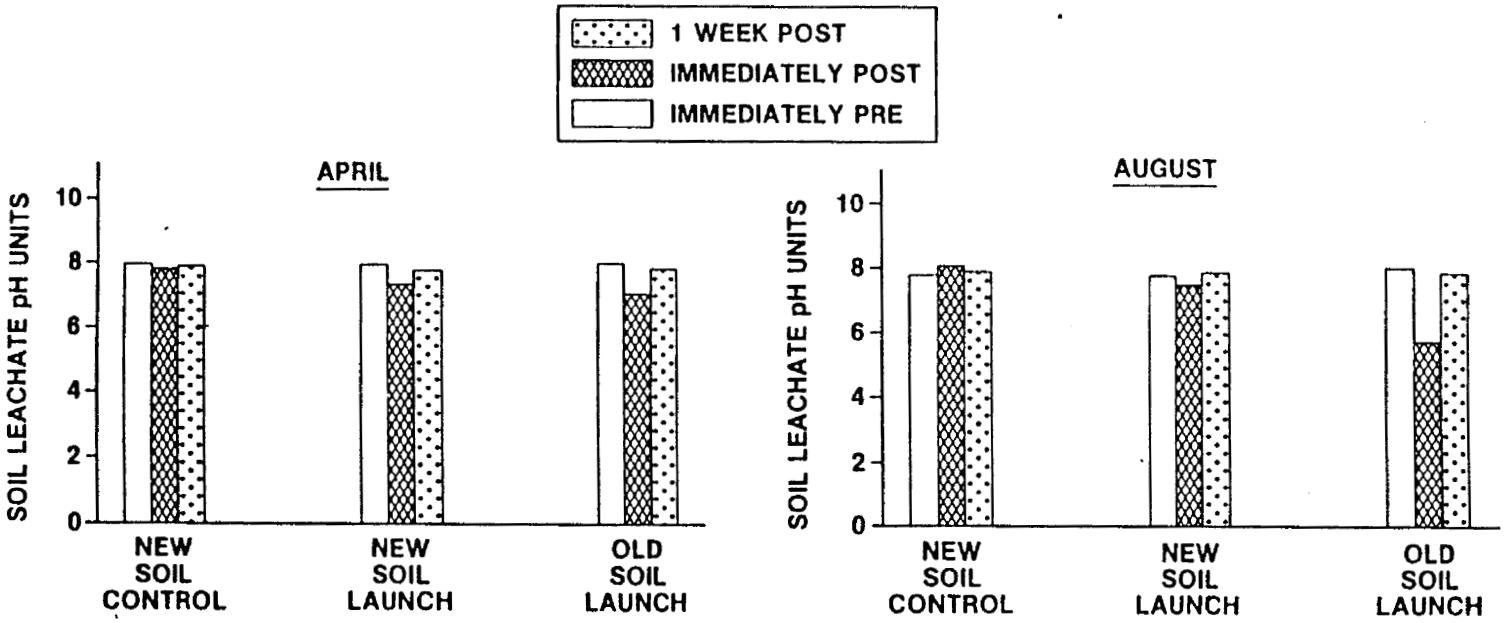




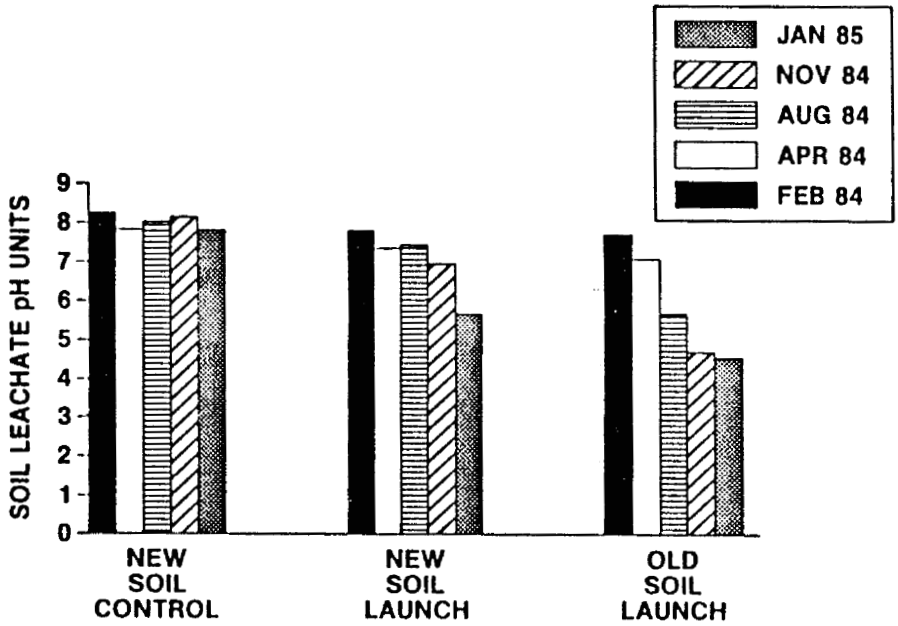


MEASUREMENTS OF LAGOONAL WATER pH SHOWED A SEVERE DROP OF UP TO 6 OR 7 UNITS. THIS pH DROP WAS MORE SEVERE IN SURFACE WATERS (< 25-30 cm DEPTH) AND NEAR THE LAUNCH PAD. WIND MIXING AND BUFFERING RETURNED THE WATERS TO NEAR BACKGROUND WITHIN 48-72 HOURS. RUNOFF FROM THE PAD AND AREAS ADJACENT TO THE LAGOON HAVE CAUSED pH DROPS ON SOME OCCASIONS. CUMULATIVE EFFECTS ON WATER pH HAVE NOT OCCURRED.

pH OF SOIL LEACHATE PRE AND POST LAUNCH

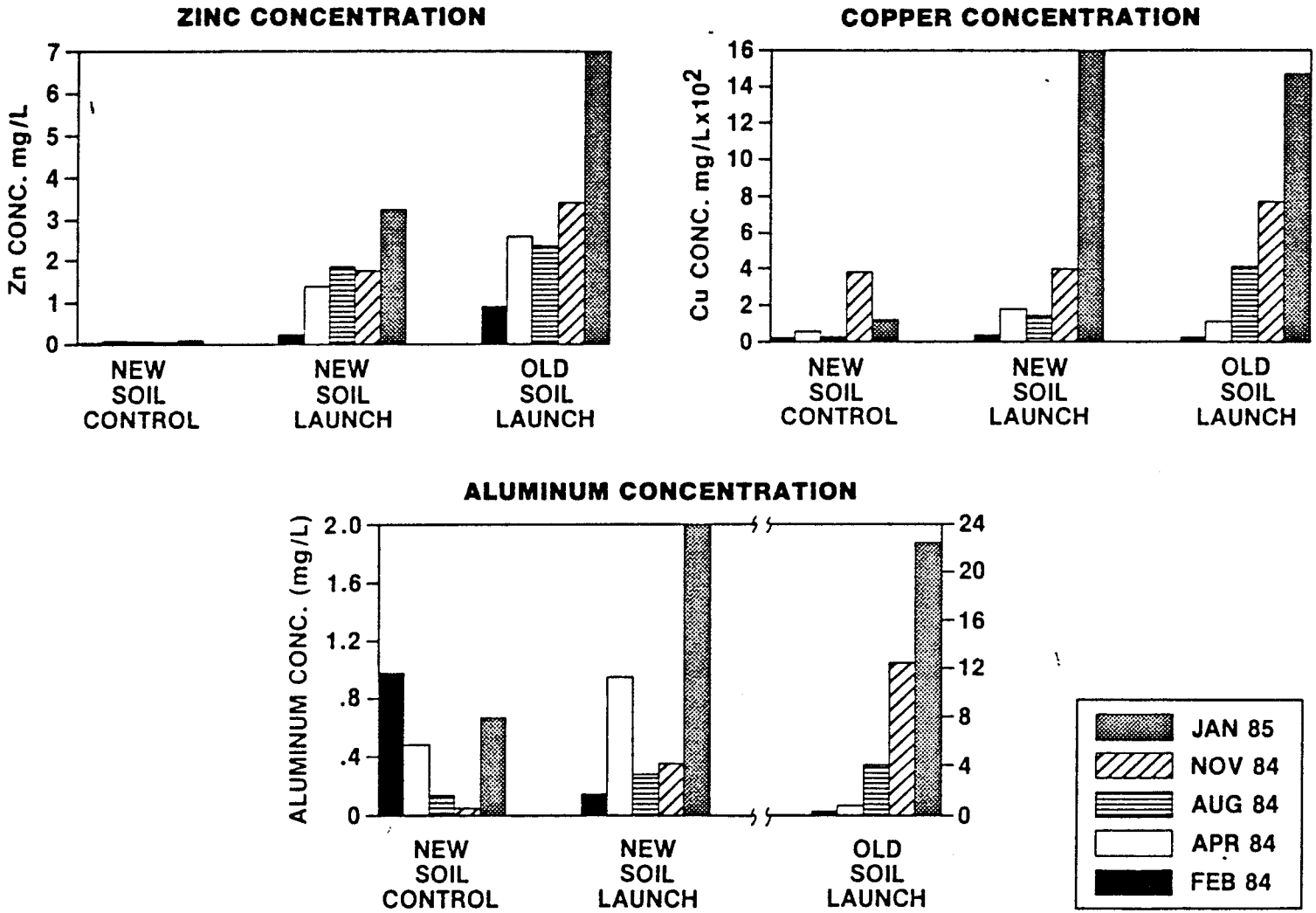


pH OF SOIL LEACHATE IMMEDIATELY POST LAUNCH UNCOVERED MICROCOSMS



MICROCOSM SOIL LEACHATE BUFFERED TO NEAR PRELAUNCH pH WITHIN SEVEN DAYS. THE pH DECREASE WAS GREATER WITH EACH LAUNCH.

LEACHATE IMMEDIATELY POST LAUNCH — UNCOVERED MICROCOSMS



METALS CONCENTRATIONS INCREASED IN SOIL MICROCOSM LEACHATES WITH REPEATED EXPOSURE DUE IN PART TO DEPOSITION OF METALS FROM THE LAUNCH CLOUD AND DECREASED SOIL pH

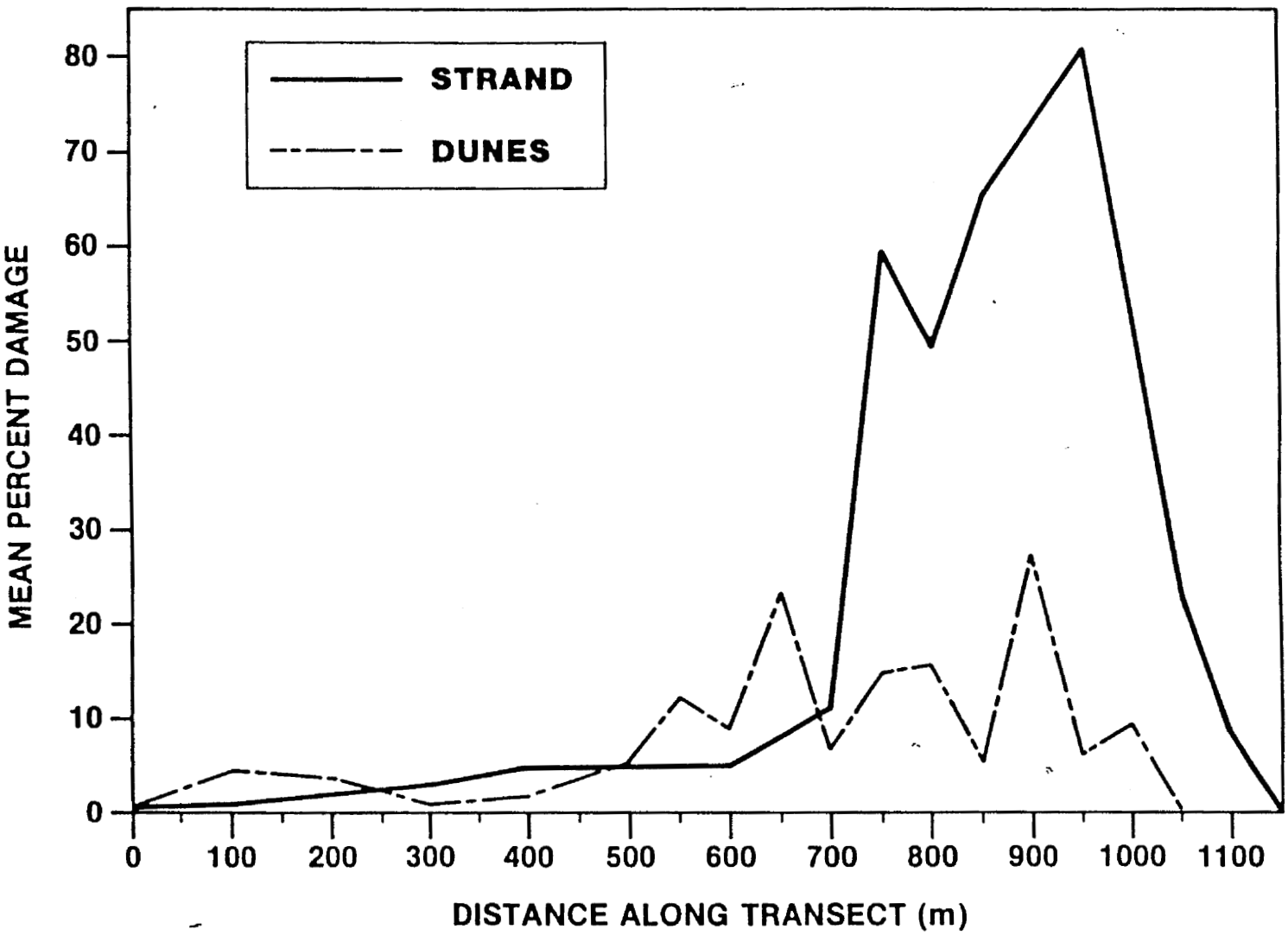
MEAN SPECIES RICHNESS AND MEAN PERCENT COVER FROM STS-1 THROUGH STS-9

SPECIES	ALL PLOTS (N = 42)	SEVERE IMPACT (N = 23)	MODERATE IMPACT (N = 19)
# POST STS-1	7.8	9.2	6.0
# POST STS-9	5.1 *	5.2 *	4.9
# IN COMMON	3.4	2.9	4.0
# LOST	4.3	6.3	1.9
# GAINED	1.7	2.3	0.9
TOTAL COVER POST STS-1 (%)	125.8	118.8	134.2
TOTAL COVER POST STS-9 (%)	78.6 *	69.9 *	89.2*

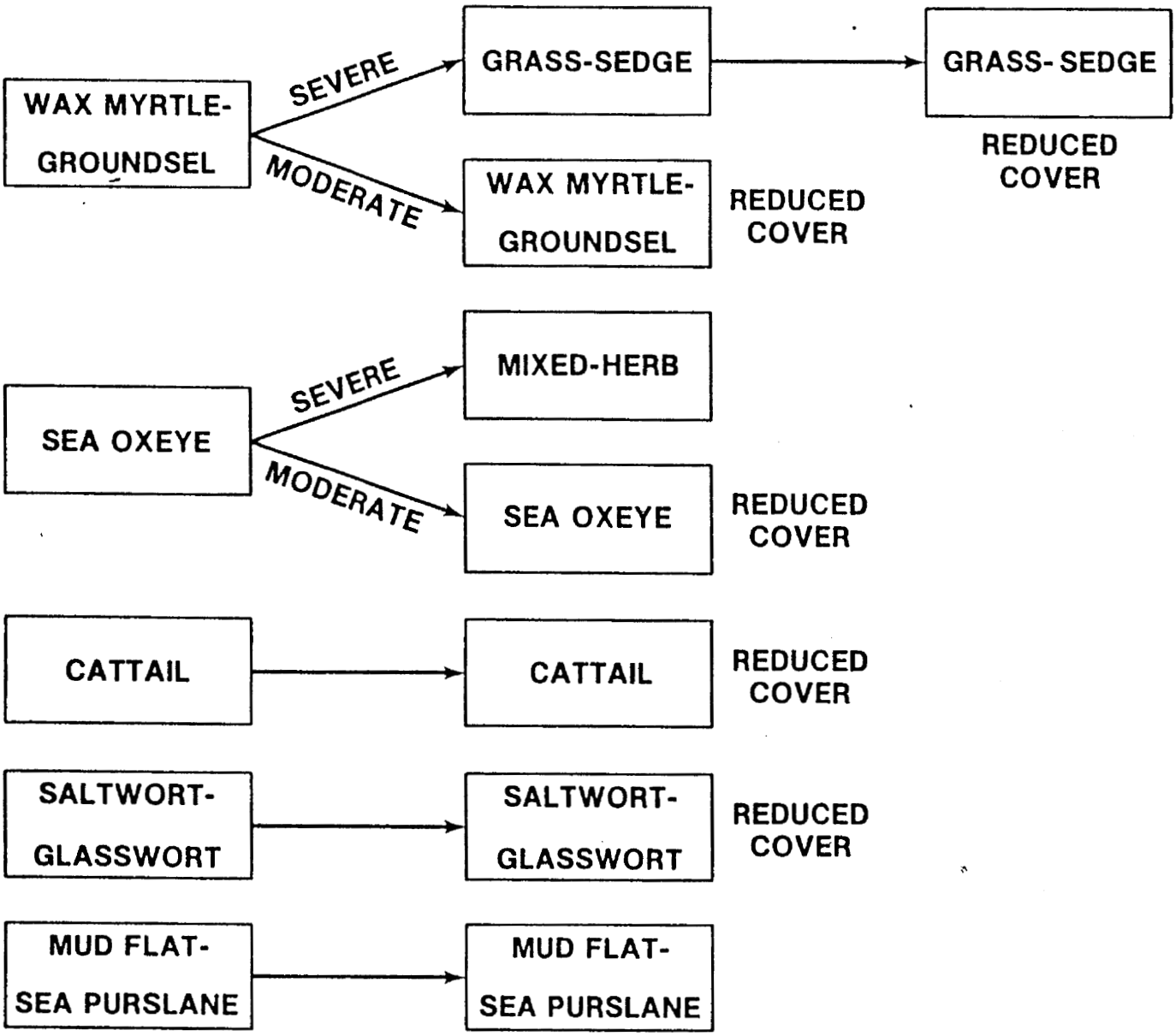
* $P < 0.05$

CHANGES IN VEGETATION IN THE NEAR-FIELD IMPACT ZONE INCLUDE REDUCTION IN SPECIES RICHNESS (NUMBER) AS SENSITIVE SPECIES ARE LOST AND REDUCTION IN COVER AS THE SHRUB LAYER IS KILLED.

STS-8 VEGETATION DAMAGE



VEGETATION DAMAGE WAS ASSESSED ACROSS THE WIDTH OF THE AREA OF **STRAND** AND **DUNE** VEGETATION IMPACTED BY STS-8. PERCENT COVER AND PERCENT DAMAGE BY SPECIES WERE DETERMINED ON 1 m^2 PLOTS. MEAN PERCENT DAMAGE WAS DETERMINED AS A WEIGHTED AVERAGE.



RETROGRESSIVE CHANGES IN PLANT COMMUNITIES IN THE PAD 39A NEAR-FIELD IMPACT ZONE AFTER NINE LAUNCHES. ALL AREAS OF SEVERE IMPACT HAVE LOST ALL SHRUB COVER AFTER 24 LAUNCHES AND SOME AREAS ARE DENUDED.

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